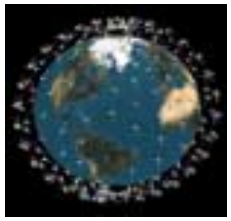
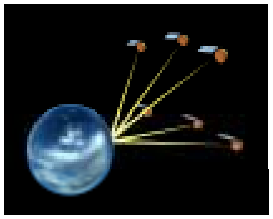
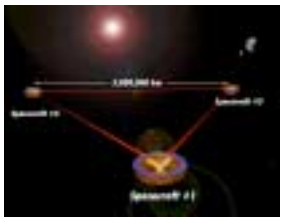
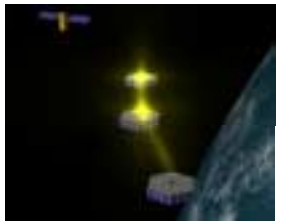
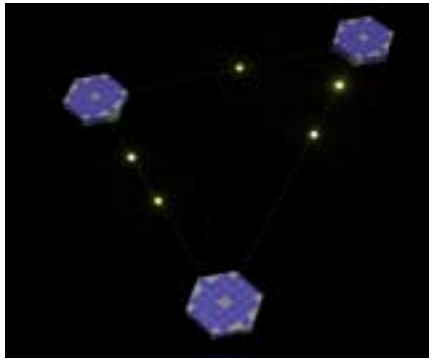
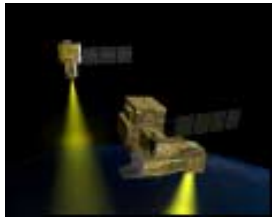





Distributed Space Systems

Nanosat Demonstrations

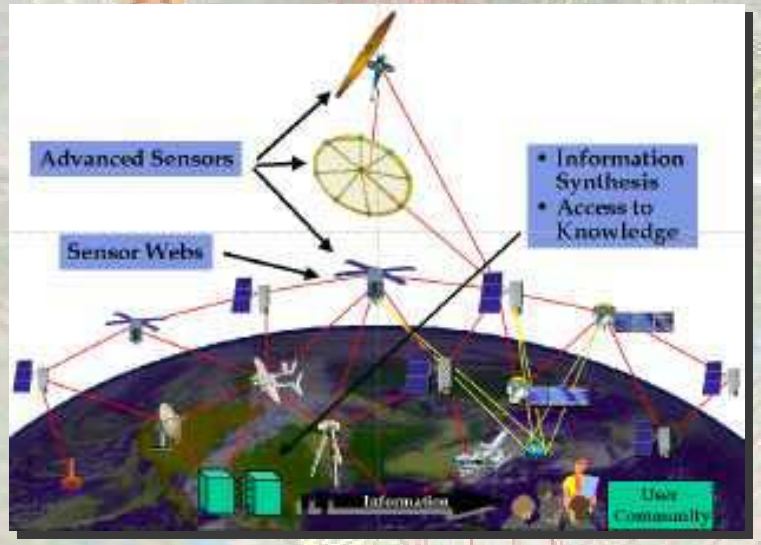
Dr. Jesse Leitner
GSFC DSS Lead Engineer
Jesse.Leitner@gsfc.nasa.gov
301-286-2630

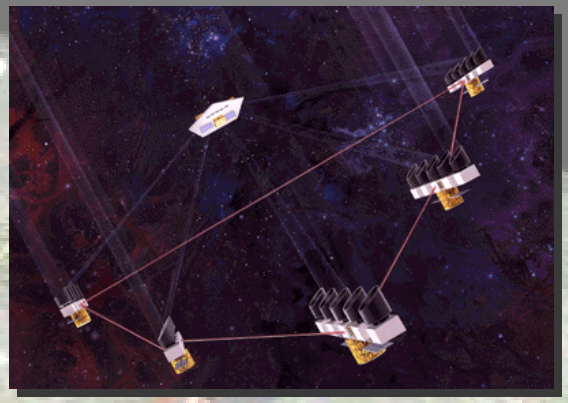

April 2, 2002

Distributed Space Systems- Revolutionizing Earth & Space Science

Co-observation

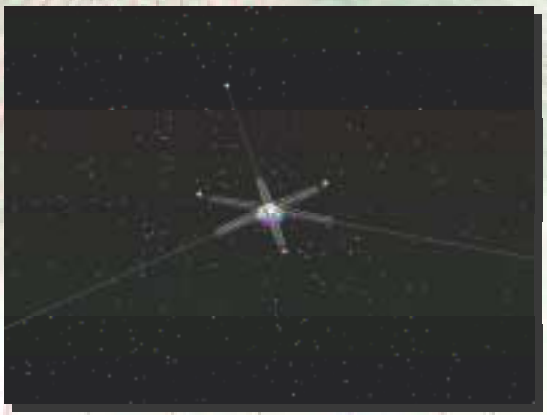


Coincidental Observations



Interferometry

Multi-point observation



Tethered Interferometry

A new era of space exploration will be enabled by cooperating spacecraft

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Distributed Spacecraft Missions

Projected Launch Year	Mission Name	Mission Type
00	New Millennium Program (NMP) Earth Observing-1 (2)	Earth Science
01	Gravity Recovery and Climate Recovery (GRACE) (2)	Earth Science
03	University Nanosats (AFRL/GSFC) ORION nanosat mission (2)	Technology Demonstrator
03	University Nanosats (AFRL) 3 Corner Sat misson (3)	Technology Demonstrator
03	University Nanosats (AFRL/GSFC) ION-F mission (3)	Technology Demonstrator
03	Synchronized Position Hold Engage & Reorient Experimental Satellites	Technology Demonstrator
03	NMP ST-5 Nanosat Constellation Trailblazer (3)	Space Science
04	Techsat-21/AFRL (3)	Technology Demo
04	Auroral Multiscale Mission (AMM)/APL	Space Science/SEC
04	ESSP-3-Cena (w/ Aqua) (2)	Earth Science
05	Starlight (ST-3) (2)** (ground-based only at the moment)	Space Science/ASO
05	Magnetospheric Multiscale (MMS) (4)	Space Science/SEC
06	MAGnetic Imaging Constellation (MAGIC) (7, string of pearls)	Space Science
06	COACH (2-3)	Earth Science
07	Global Precipitation Mission (EOS-9)	Earth Science
07	Geospace Electrodynamic Connections (GEC)	Space Science/SEC
08	Constellation-X (4)	Space Science/SEU
08	Magnetospheric Constellation (DRACO) (50-100)	Space Science/SEC
08	Laser Interferometer Space Antenna (LISA) (3)	Space Science/SEU
09	DARWIN Space Infrared Interferometer/European Space Agency	Space Science
10	Leonardo (GSFC) (4-8)	Earth Science
15	Stellar Imager (SI) (10-30)	Space Science/ASO
	Astronomical Low Frequency Array (ALFA)/Explorers	Space Science
12	MAXIM Pathfinder (2-3)	Space Science/SEU
05+	Living with a Star (LWS) (many)	Space Science
05+	Soil Moisture and Ocean Salinity Observing Mission (EX-4)	Earth Science
05+	Time-Dependent Gravity Field Mapping Mission (EX-5)	Earth Science
05+	Vegetation Recovery Mission (EX-6)	Earth Science
05+	Cold Land Processes Research Mission (EX-7)	Earth Science
05+	Hercules	Space Science/SEC
05+	Orion Constellation Mission	Space Science/SEC
15	Submillimeter Probe of the Evolution of Cosmic Structure (SPECS) (3)	Space Science/SEU
20+	Planet Imager (PI)	Space Science/ASO
20	MAXIM X-ray Interferometry Mission (34)	Space Science/SEU
15+	Solar Flotilla, IHC, OHRM, OHRI, ITM, IMC, DSB Con	Space Science/SEC
15+	NASA Goddard Space Flight Center Earth Sciences Vision	Earth Science
15+	NASA Institute of Advanced Concepts/Very Large Optics for the Study of Extrasolar Terrestrial Planets	Space Science

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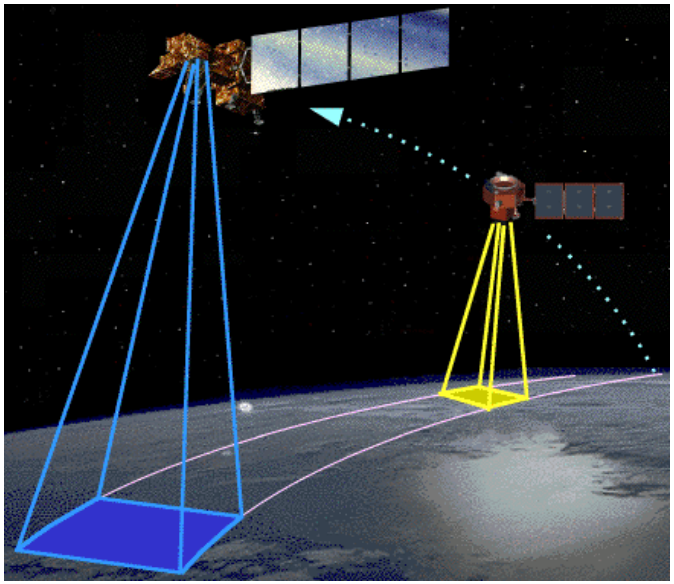
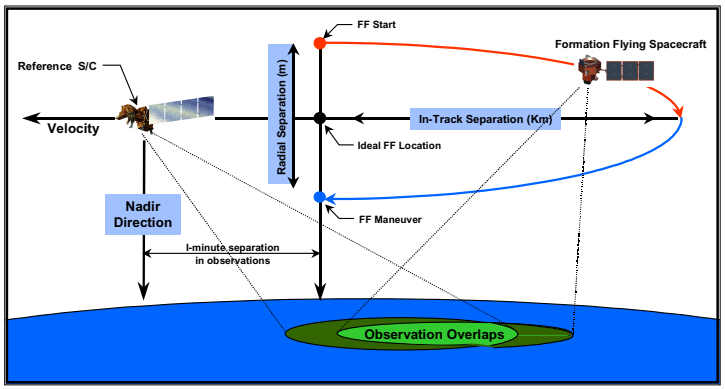
NMP EO-1 Enhanced Formation Flying (EFF) Experiment





Level - I:

Demonstrate the Capability to Fly Over the Same Ground Track As LandSat-7 Within 3 Km at a Nodal Separation Interval of Nominally One Minute During Which Time an Image Is Collected.

Level-II:

***EFF*- Shall Provide the Autonomous Capability of Flying Over the Same Groundtrack of Another S/C at Fixed Separation Times.**

***Autonomy* - Shall Provide On-Board Autonomous Relative Navigation and Formation Flying Control for EO-1 and LandSat-7.**

***AutoCon Flight Control System* - Shall Provide Autonomous Formation Flying Control Via AutoCon (to provide future reusability).**

***Ground Track* - EO-1 Shall Fly the Same Ground Track As LandSat-7.**

***Separation* - EO-1 Shall Remain Within a 1-Minute In-Track Separation from LandSat-7.**

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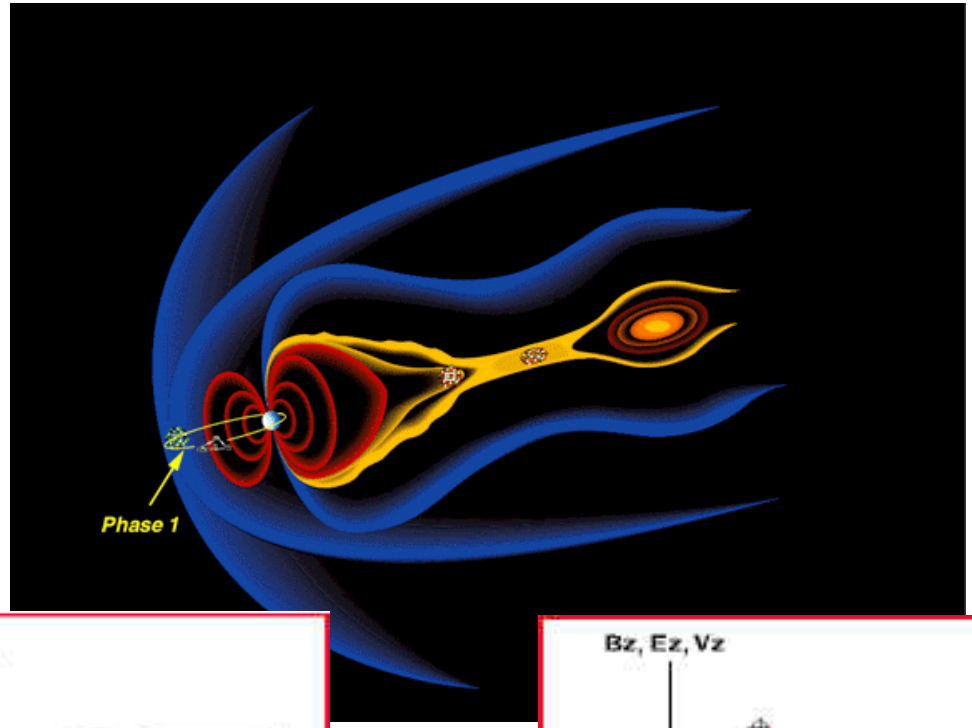
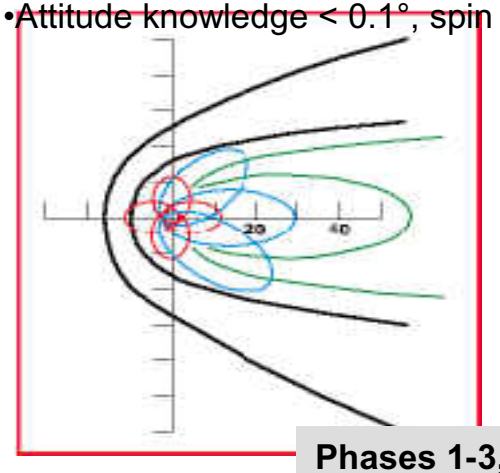
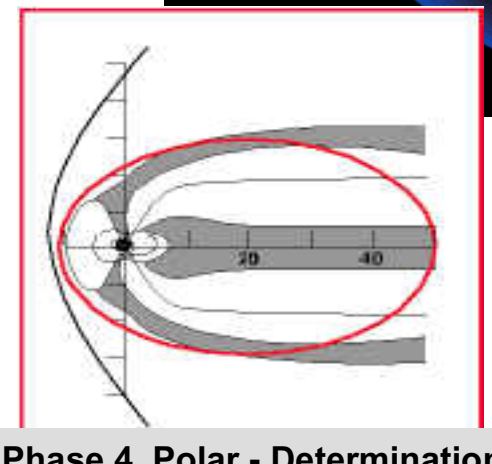
Magnetospheric Multi-scale

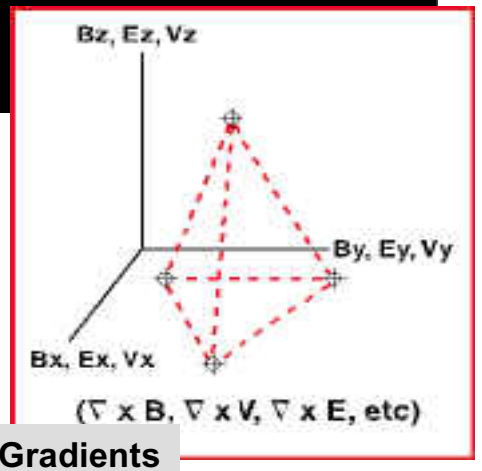
How do small-scale processes control large-scale phenomenology, such as magnetotail dynamics, plasma entry into the magnetosphere, and substorm initiation?



- 4 identical spacecraft in a variably spaced tetrahedron
  (1 km to several *earth radii*)
- 4 orbit phases, orbit adjust
- 2 year in-orbit (minimum) mission life
- Interspacecraft ranging and communication
- Advanced instrumentation, integrated payload
- Attitude knowledge < 0.1°, spin rate 20 rpm







Phases 1-3, Equatorial - Phase 4, Polar - Determination of Spatial Gradients

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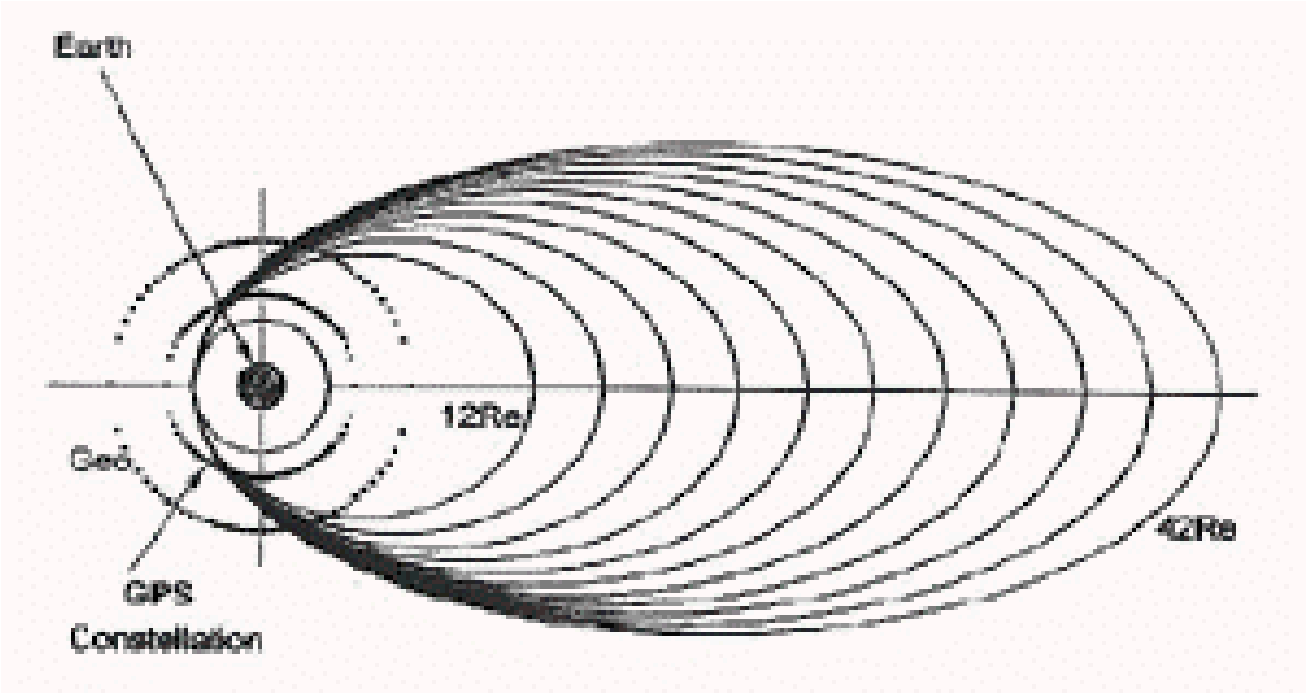
DRACO - Magnetospheric Constellation

Fundamental measurements: magnetic field, plasma flow field, and energetic particle acceleration



- **50-100 nanosatellites - "weather observatories"**
- **Orbits have 3Re perigee with varying apogees from 12Re to 42Re.**
- **Nanosats communicate with ground during perigee region.**

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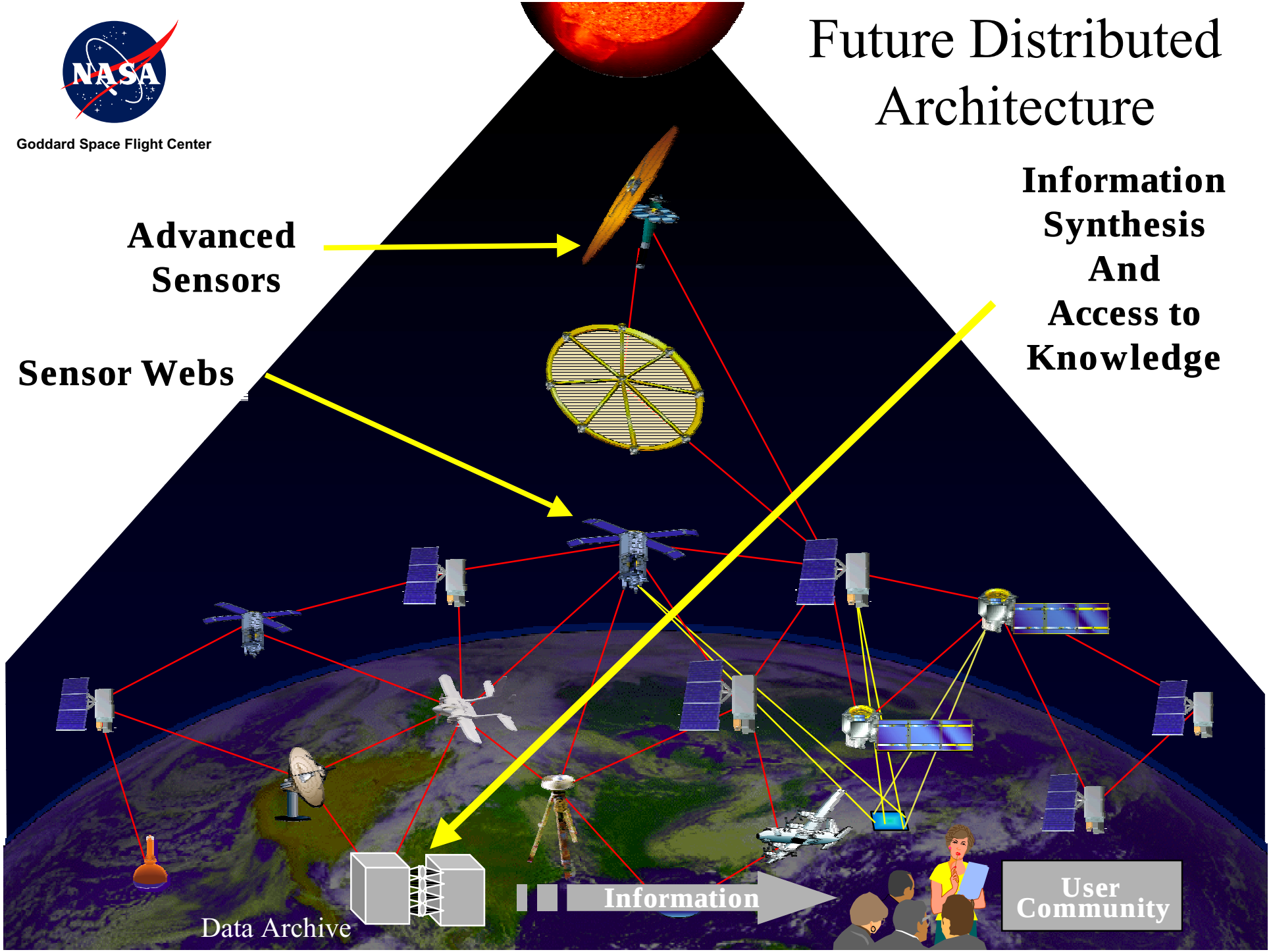
Future Distributed Architecture



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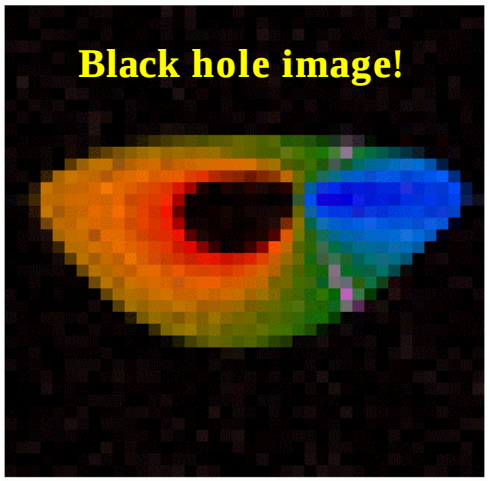
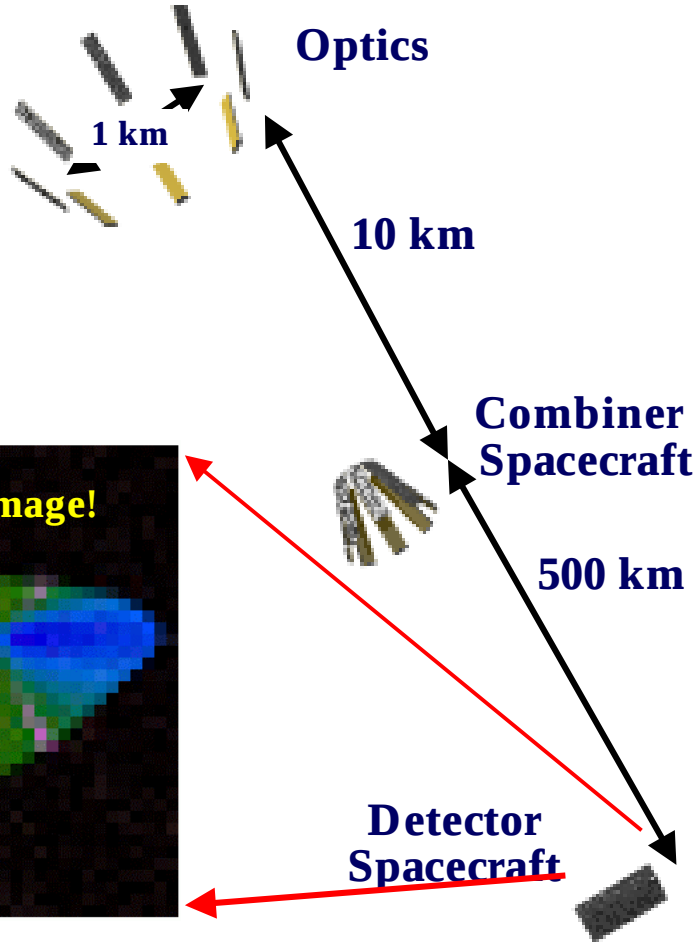
The Black Hole Imager: Micro Arcsecond X-ray Imaging Mission (MAXIM) Observatory Concept

32 optics (300 × 10 cm) held in phase with 600 m baseline to give 0.3 micro arc-sec

34 Formation Flying Spacecraft

System is adjustable on orbit to achieve larger baselines





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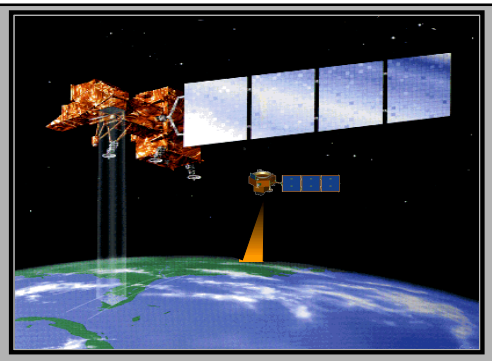
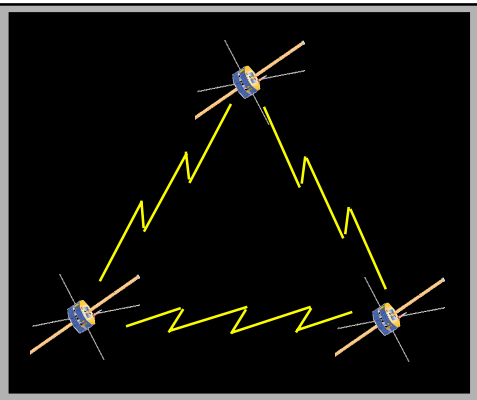
DSS Technology Development Areas



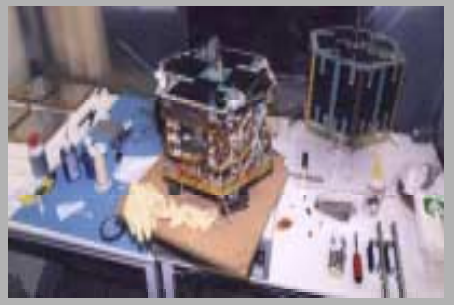
Formation Sensing and Control

Sensing, actuation, and algorithms required to maintain and/or understand vehicle position or orientation



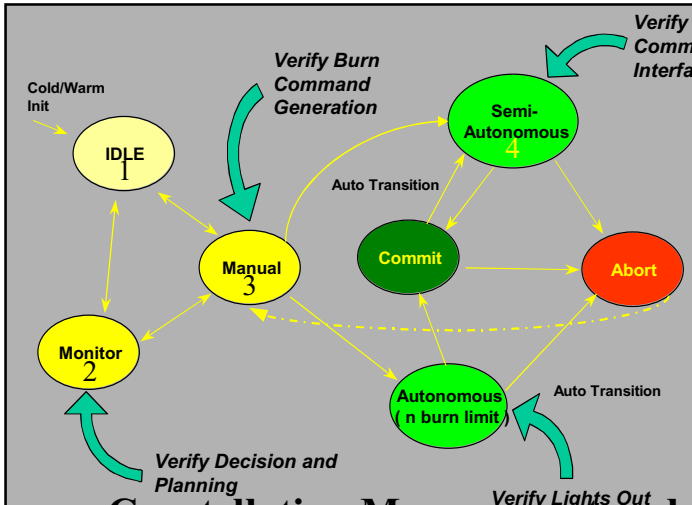
Intersatellite Communications

Hardware, software, and advanced coding and compression algorithms to satisfy unique DSS communications needs



Miniaturized Spacecraft Technology

Approaches to reducing spacecraft bus infrastructure requirements in the areas of cost,mass, volume, and power



Constellation Management and Mission Operations

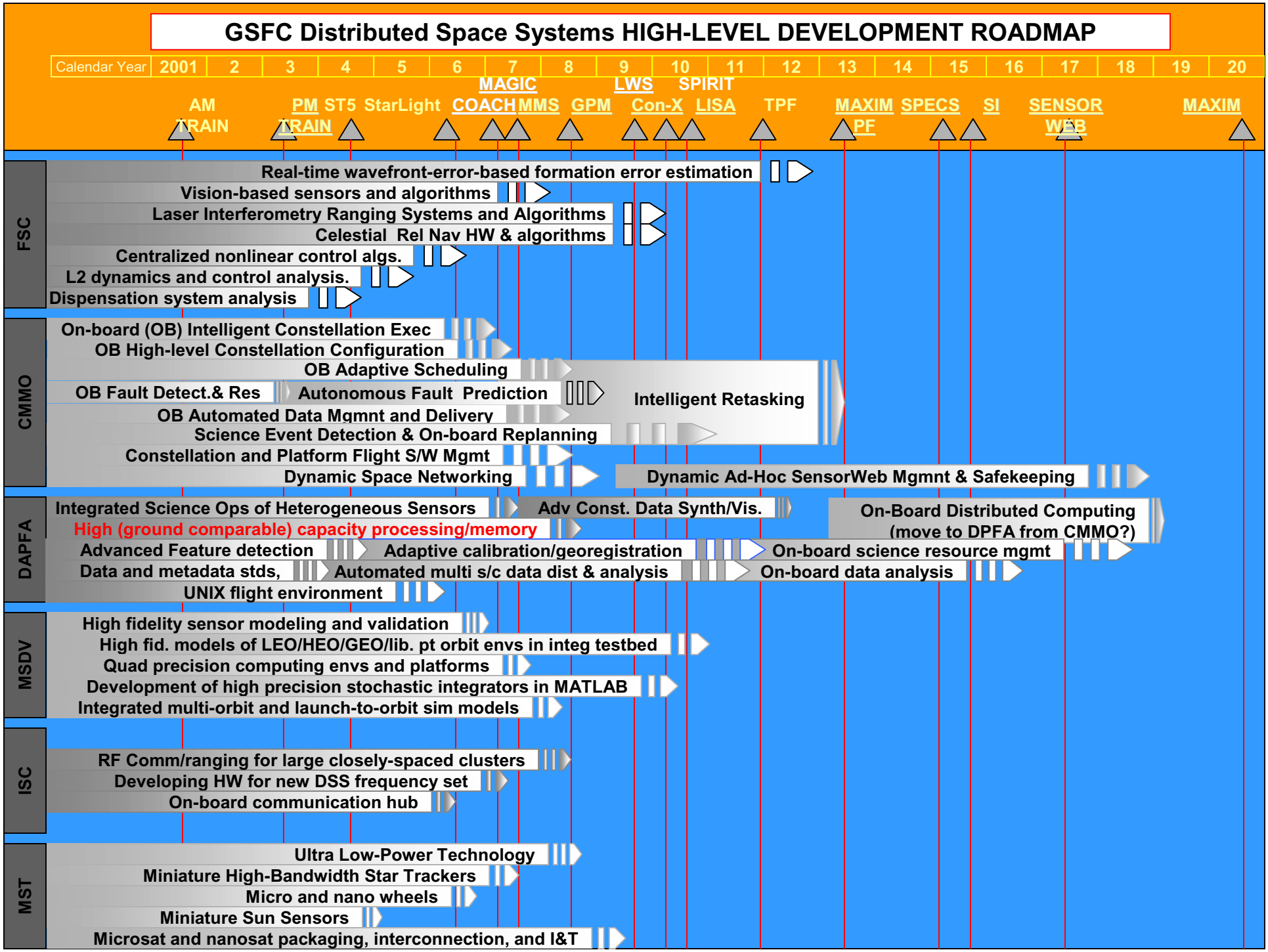
High-level control strategies to enable collaborative multi-spacecraft campaigns

Mission Synthesis, Design, and Validation

The end-to-end DSS systems analysis

Data Acquisition, Processing, Fusion, and Analysis

Data operations of the DSS E2E system in fulfilling the scientific objectives


GSFC Distributed Space Systems HIGH-LEVEL DEVELOPMENT ROADMAP
Calendar Year
2001
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
AM
TRAIN
PM
TRAIN
ST5
StarLight
MAGIC
COACH
MMS
GPM
LWS
Con-X
SPIRIT
LISA
TPF
MAXIM
PF
SPECS
SI
SENSOR
WEB
MAXIM
FSC
Real-time wavefront-error-based formation error estimation
Vision-based sensors and algorithms
Laser Interferometry Ranging Systems and Algorithms
Celestial Rel Nav HW & algorithms
Centralized nonlinear control algs.
L2 dynamics and control analysis.
Dispensation system analysis
CMMO
On-board (OB) Intelligent Constellation Exec
OB High-level Constellation Configuration
OB Adaptive Scheduling
OB Fault Detect.& Res
Autonomous Fault Prediction
Intelligent Retasking
OB Automated Data Mgmnt and Delivery
Science Event Detection & On-board Replanning
Constellation and Platform Flight S/W Mgmt
Dynamic Space Networking
Dynamic Ad-Hoc SensorWeb Mgmnt & Safekeeping
DAPFA
Integrated Science Ops of Heterogeneous Sensors
Adv Const. Data Synth/Vis.
On-Board Distributed Computing
(move to DPFA from CMMO?)
High (ground comparable) capacity processing/memory
Advanced Feature detection
Adaptive calibration/georegistration
On-board science resource mgmt
Data and metadata stds,
Automated multi s/c data dist & analysis
On-board data analysis
UNIX flight environment
MSDV
High fidelity sensor modeling and validation
High fid. models of LEO/HEO/GEO/lib. pt orbit envs in integ testbed
Quad precision computing envs and platforms
Development of high precision stochastic integrators in MATLAB
Integrated multi-orbit and launch-to-orbit sim models
ISC
RF Comm/ranging for large closely-spaced clusters
Developing HW for new DSS frequency set
On-board communication hub
MST
Ultra Low-Power Technology
Miniature High-Bandwidth Star Trackers
Micro and nano wheels
Miniature Sun Sensors
Microsat and nanosat packaging, interconnection, and I&T

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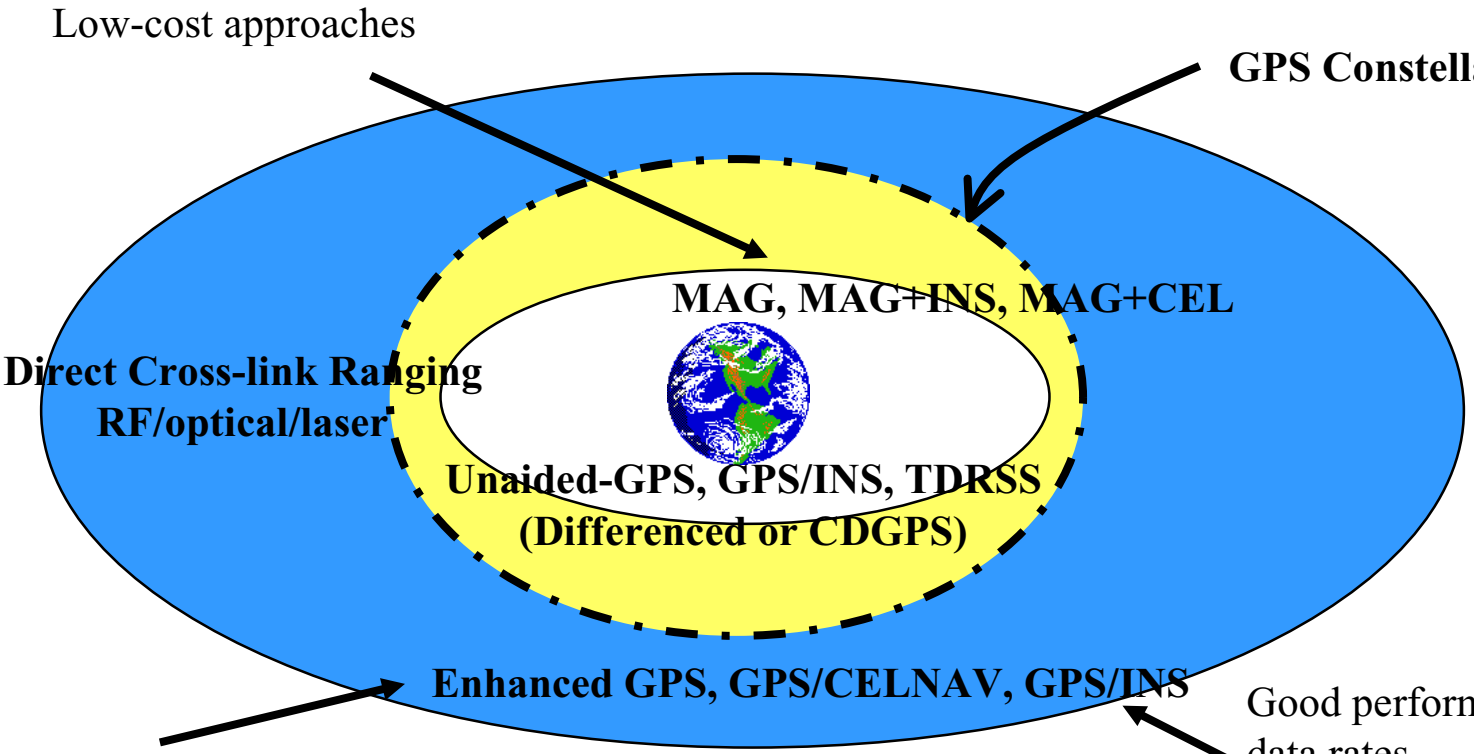
Relative Navigation



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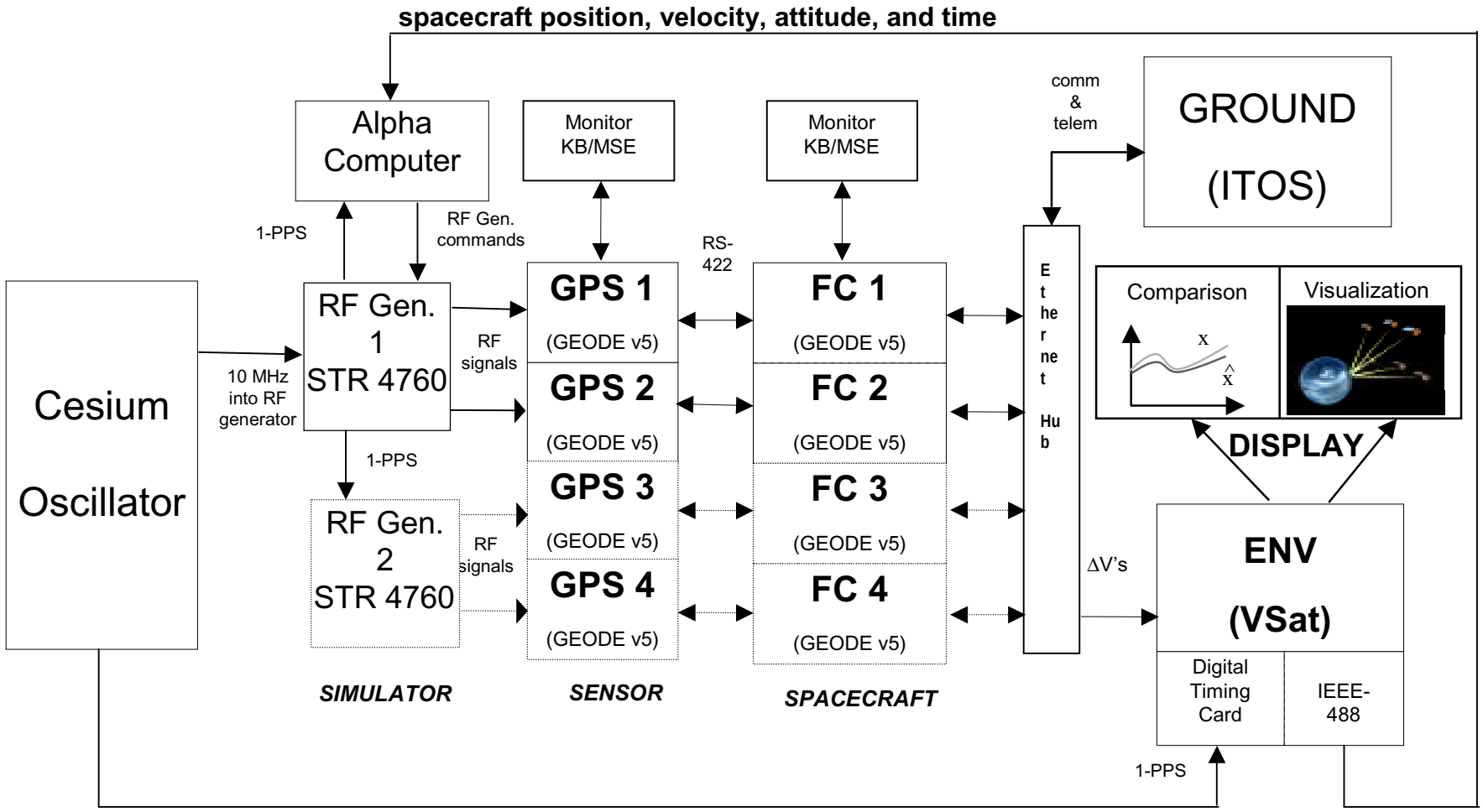
Decentralized Control Full Capability

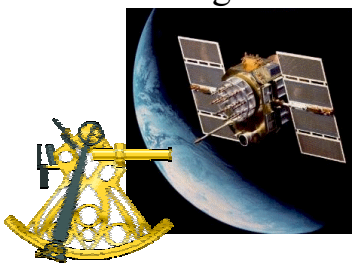


NASA & the AFRL University Nanosat Program

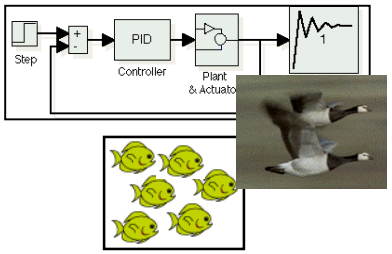
NASA

Distributed Space Systems Technology Program
(Code R, ESTO, GMSEC, NMP, SBIR, ...)

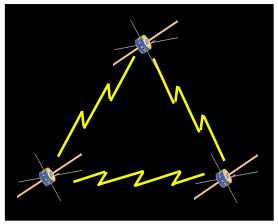
(relative) navigation system technologies



fleet and vehicle control systems



inter-spacecraft comm



DoD

University Nano-Satellite Program
(AFRL, AFOSR, DARPA)

New Mexico State
"3^SAT"

Santa Clara
"Emerald"

Univ of Colorado
"3^SAT"

Stanford
"Emerald"

Arizona State
"3^SAT"

AFRL
(nanotechnology demo)

Carnegie Mellon
"Solar Blade"

Virginia Tech
"VTISMM"

GSFC
(formation flying demo)

Univ of Washington
"UofW Nanosat"

Utah Stat
"USUSat"

Boston U
"Constellation Pathfinder"

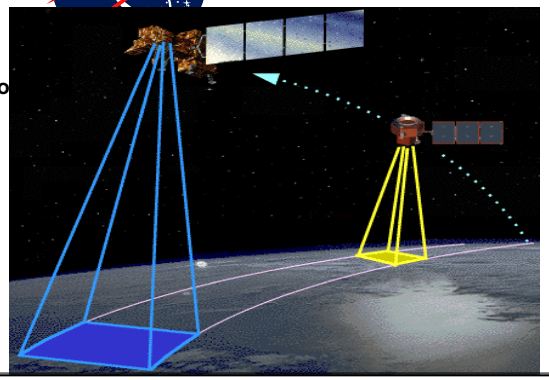
technologies

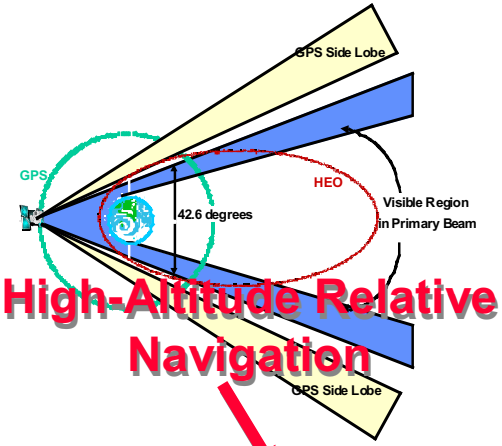
University Nano-Satellites
for
Distributed Spacecraft Control

vehicles

interaction - cooperation - collective behavior

Integration and Infusion of DSS Technologies

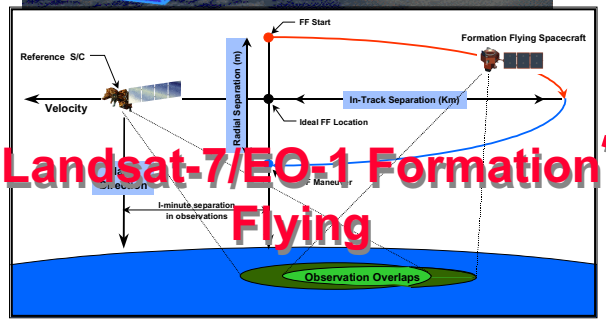




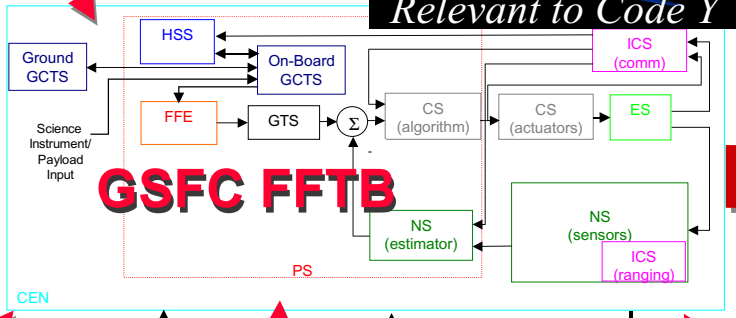
High-Altitude Relative Navigation

MMS Mission HI-FI E2E Integrated HWIL Sim

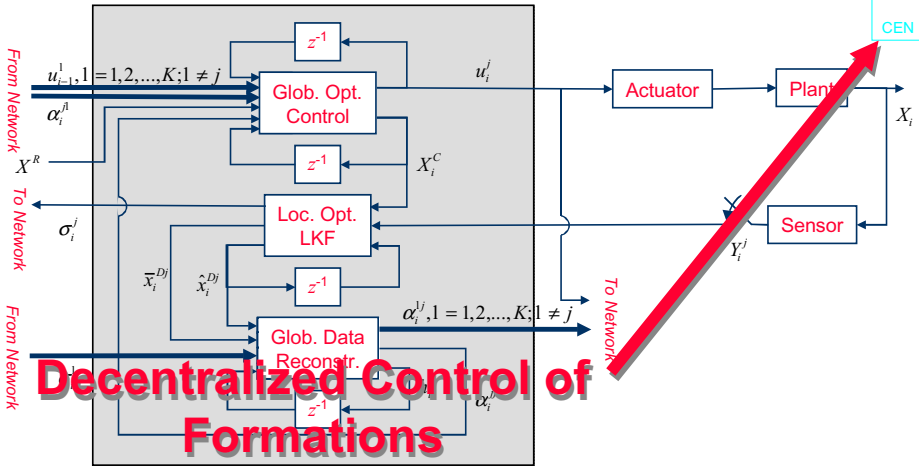
Code S Mission with Technologies Relevant to Code Y



Landsat-7/EO-1 Formation Flying



GSFC FFTB



Decentralized Control of Formations

External Testbeds and facilities

GUI Input

DISPLAY

University NanoSats & Intersatellite Comm.

- SOMO
- DDF
- Outside Partners

DSS- integrating and validating systems solutions to enable Enterprise multi-spacecraft missions

Formation Flying Space Testbed: ORION

- Operational Characteristics
  - Mass: ~ 40 kg
  - Size: 45 cm cube
  - T_{max}: 0.2 N / thruster
  - ITB/M: 100 μm/s
  - MTL/M: 0.01 m/s²

- GN_2 Propulsion System
  - 12 thrusters: 4x3 asymmetric
  - I_{sp} ~ 70 sec
  - ΔV_{total}: 25 m/s
  - torquer coils for detumbling

- Active station-keeping (cold gas) and 3-axis stabilization
- Advanced inter-spacecraft communication
- Relative sensing and control (carrier phase differential GPS).

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ORION2 Experiment Objectives

- **Provide a comprehensive on-orbit demonstration of true formation flying spacecraft**
  - Demonstrate technologies to enable a ***virtual platform***
  - GPS sensing and fleet control
  - Significant interest from both NASA & USAF
  - **Demonstrates the key technology element to be used on the TechSat-21 mission** *(prototype of same hardware, algorithms, and software)*
- **Low-cost to NASA**
  - Micro-satellites developed using techniques from the Space Systems Development Laboratory.
- **High-risk, but**
  - Most technology developed in-house, so no major investments.

Technical Goals

- **Demonstrate control for a cluster of micro-satellites.**
  - Real-time autonomous control software
  - Formation directed at a high-level from the ground.
- **Demonstrate GPS receiver for real-time attitude & relative navigation**
  - First on-orbit demonstration of CDGPS for precise relative navigation and control
  - Expect <<1 m (relative - radial) for determination & 5 m (relative - radial) for control.
  - Low-power, low-cost, attitude capable GPS receiver.
- **Various control architectures, real-time inter-vehicle communications link, and local ranging systems**

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Current status

- **Funding from GSFC**
  - FY00: $1+M (SOMO+ Explorers + CETDP)
  - FY01: $1+M (SOMO + CETDP)
  - FY02: $200k (after Code R cuts)
- **Students transitioned into the workforce**
  - AFRL, GSFC, Industry - dozens
- **Launches planned in late 2003**
- **Currently OSC shuttle safety support team is reviewing ION-F and ORION end-to-end.**
- **Integration for ORION and ION-F to take place at GSFC**
  - Need to transfer sponsorship to NASA
- **Integration for 3 CornerSat to take place at AFRL**
  - DoD sponsorship in place, via SERB process (STP)

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Lessons Learned

- **Plan from the start on successful flight as end goal**
  - Education is key, but ride commitments expect delivery
- **Carefully consider delineation of spacecraft development and assembly tasks between the universities and government/industry organizations**
  - Safety process should involve safety experts
  - Try to minimize the use of students in performing very mundane but tedious tasks
- **Carefully consider contract and agreement mechanisms among all parties involved.**
- **Plan as a long-term activity, not year-by-year**